Ocean Surface Wave Optical Roughness – Innovative Measurement and Modeling

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LONG-TERM GOALS

We are part of a multi-institutional research team* funded by the ONR-sponsored Radiance in a Dynamic Ocean (RaDyO) program. The primary research goals of the program are to (1) examine time-dependent oceanic radiance distribution in relation to dynamic surface boundary layer (SBL) processes; (2) construct a radiance-based SBL model; (3) validate the model with field observations; and (4) investigate the feasibility of inverting the model to yield SBL conditions. The goals of our team are to contribute innovative measurements, analyses and models of the sea surface roughness at length scales as small as a millimeter. This characterization includes microscale and whitecap breaking waves.

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OBJECTIVES

Nonlinear interfacial roughness elements - sharp crested waves, breaking waves as well as the foam, subsurface bubbles and spray they produce, contribute substantially to the distortion of the optical transmission through the air-sea interface. These common surface roughness features occur on a wide range of length scales, from the dominant sea state down to capillary waves. Wave breaking signatures range from large whitecaps with their residual passive foam, down to the ubiquitous centimeter scale microscale breakers that do not entrain air. There is substantial complexity in the local wind-driven sea surface roughness microstructure. Traditional descriptors of sea surface roughness are scale-integrated statistical properties, such as significant wave height, mean squared slope (Cox and Munk, 1954) and breaking probability (Holthuijsen and Herbers, 1986). Subsequently, spectral characterizations of wave height, slope and curvature have been measured, providing a scale resolution into Fourier modes for these geometrical sea roughness parameters. More recently, measurements of whitecap crest length spectral density (Phillips et al, 2001, Gemmrich, 2005) and microscale breaker crest length spectral density (Jessup and Phadnis, 2005) have been reported.

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Our effort seeks to provide a more comprehensive description of the physical and optical roughness of the sea surface. We will achieve this by implementing a comprehensive sea surface roughness observational 'module' within the RADYO field program to provide optimal coverage of the fundamental optical distortion processes associated with the air-sea interface. Within our innovative complementary data gathering, analysis and modeling effort, we will pursue both spectral and phase-resolved perspectives. These will contribute directly towards refining the representation of surface wave distortion in present air-sea interfacial optical transmission models.

APPROACH

We will build substantially on our accumulated expertise in sea surface processes and air-sea interaction. We are working within the larger team (listed above) measuring and characterizing the surface roughness. The group plans to contribute the following components to the primary sea surface roughness data gathering effort in RaDyO:

- *polarization camera measurements* of the sea surface slope topography, down to capillary wave scales, of an approximately 1m x 1m patch of the sea surface (see Figure 1), captured at video rates. [Schultz]

- *co-located and synchronous orthogonal 75 Hz linear scanning laser altimeter* data to provide spatio-temporal properties of the wave height field (resolved to O(0.5m) wavelengths) [Banner, Morison]

- *high resolution video imagery* to record whitecap data, from two cameras, close range and broad field [Gemmrich]

- *fast response, infrared imagery* to quantify properties of the microscale breakers, and surface layer kinematics and vorticity [Zappa]

- *sonic anemometer* to characterize the near-surface wind speed and wind stress [Zappa]

Our envisaged data analysis effort will include: detailed analyses of the slope field topography; laser altimeter wave height and large scale slope data; statistical distributions of whitecap crest length density in different scale bands of propagation speed and similarly for the microscale breakers, as functions of the wind speed/stress and the underlying dominant sea state. Our contributions to the modeling effort will focus on using the data to refine the sea surface roughness transfer function. This comprises the representation of nonlinearity and breaking surface wave effects including bubbles, passive foam, active whitecap cover and spray, as well as microscale breakers.

WORK COMPLETED

Our effort in FY07 has been primarily directed toward detailed planning and design of the suite of sea surface roughness measurements that we will undertake during the Scripps Institute of Oceanography (SIO) Pier Experiment scheduled for January 6-28, 2008. During FY07 we refined our choices of the instrumentation needed to make the measurements described in the preceding section, and continued work on the analysis techniques for characterizing the various roughness features. We participated in the FY07 RaDyO scientific planning meetings, which were held in Montreal in October 2006 and at SIO in June 2007.

A portion of our research team, Christopher Zappa, Michael Banner, and Howard Schultz completed the analysis of a proof-of-concept study[1] to assess the effectiveness of a new passive optical technique based on polarimetry. The Polarimetric Slope Sensing (PSS) concept exploits the scattering properties of light from the air-water boundary to recover the instantaneous two-dimensional slope field of a water surface. In principle, the polarization vector properties [polarization orientation and degree of linear polarization] of the sea surface reflection of incident skylight provide sufficient information to determine the local surface slope vector normal [F, Y] relative to the camera orientation. A controlled laboratory tank experiment was carried out with mechanically-generated gravity waves at Lamont-Doherty Earth Observatory. The second phase of this study was performed from the Piermont pier on the Hudson River, near Lamont Doherty Earth Observatory. The results discussed below are about to be submitted for publication[2].

Based on the results of the feasibility study Dr. Howard Schultz submitted an application for a DURIP award to construction of two prototype imaging polarimeters and associated equipment. The award was granted[3] and a contract was given to Polaris Sensor Technologies to design and fabricate the imaging polarimeter prototypes.

RESULTS

Instrumentation proposed for the Scripps Institution of Oceanography pier experiment, January 6-28, 2008.

The instrumentation complement that will be deployed in this filed testing phase is shown below in Figure 1.

Banner/Morison plan to deploy two orthogonal line scanning lidars, synchronized for zero crosstalk.

These will be positioned on the boom so that their intersection point is within the common footprint of the polarimetric (Schultz), infrared (Zappa) and visible (Gemmrich) imagery cameras to measure small-scale surface roughness features and breaking waves.

Zappa will deploy his infrared/visible camera system (with blackbody target, a blackbody controller, a laser altimeter). He will also deploy his environmental monitoring system (sonic anemometer, a Licor water vapor sensor, a Vaisala RH/T/P probe, a motion package, a pyranometer, and a pyrgeometer).

Gemmrich will deploy 2 video visible imagery cameras. One camera will be mounted on the main boom next to our other instrumentation packages. The second camera will be mounted higher up to provide a wider perspective on larger scale breaking events.

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[1] PI: Chris Zappa, Title "Ocean Surface Wave Optical Roughness: Innovative Polarization Measurement" ONR award number: N00014-06-1-0372.
[2] Zappa, C.J., M.L. Banner, H.J. Schultz, A. Corrada-Emmanuel, L.B. Wolff, & J. Yalcin, 2007, Polarization imagery of a water surface for short ocean wave slope retrieval, Measurement and Science Technology
[3] PI: Howard Schultz, Title: "Equipment in Support for Polarimetric Imaging," Award: N00014-07-1-0731

2008 SIO PIER EXPERIMENT INSTRUMENTATION SCHEMATIC

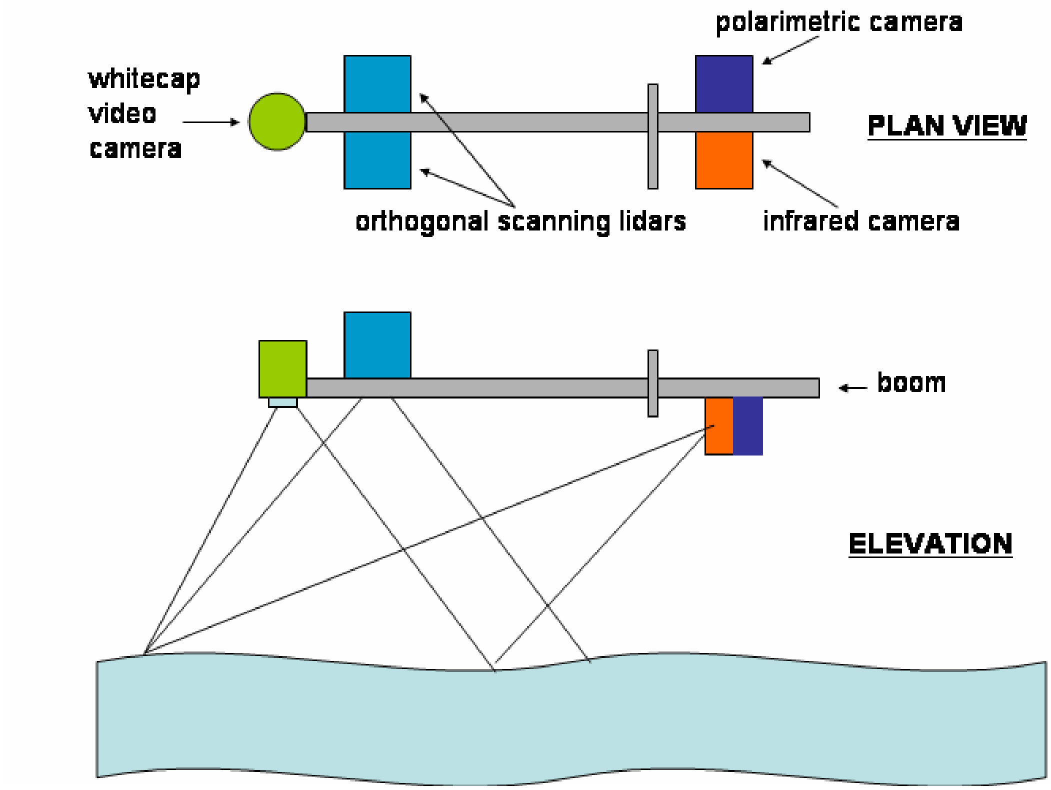

Figure 1. Schematic of instrumentation packages to be deployed from the northern swinging boom at the end of the Scripps pier. The end of the instrumentation boom will be about 9m from the edge of the pier and about 10m above the mean water level. The approximate field of view of the various instruments is shown. There is another wide angle whitecap video camera mounted well above the boom.

Schultz/Corrada-Emmanuel will deploy an instrument package located on the boom that includes a polarimetric camera imaging the very small-scale waves, an autofocus controller for this camera, a laser rangefinder for the autofocus mechanism, a polarimetric camera looking up at the sky and a motion package.

The feasibility study validated the Polarimetric Slope Sensing concept. We demonstrated that the two-dimensional slope field of short gravity wave could be accurately recovered from a distance without interfering with the fluid dynamics of the air or water, and these recovered water surface shapes appear remarkably realistic. The combined field and laboratory results demonstrate that the polarimetric camera gives a robust characterization of the fine-scale surface roughness features that are intrinsic to wind-driven air-sea interaction processes.

We were able to draw several conclusions about the instrument requirements for future studies. A complete test of the concept would require two polarimetric cameras – one that measures the incoming sky radiance, the other that measures the reflected (or refracted) radiance. The camera should have a dynamic range capable of imaging in non-uniformly illuminated sky conditions. It would be desirable for the polarimetric cameras to be able to measure the complete four-component Stokes vector. In realistic field conditions, sky radiance is often partially polarized. Furthermore, reflection of linear polarized skylight adds a small, but measurable circular polarized component. The surface-viewing camera should have an integration time fast enough to freeze the motion of short gravity wave riding on ocean swell, and a frame rate fast enough to capture their temporal structure.

IMPACT/APPLICATIONS

This effort will provide a far more detailed characterization of the wind driven air-sea interface, including wave breaking (whitecaps and microscale breaking). This is needed to provide more complete parameterizations of these processes, which will improve the accuracy of ocean optical radiative transfer models and trans-interfacial image reconstruction techniques.

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PUBLICATIONS

None